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Three-dimensional virtual planning and intraoperative navigation for two-jaw orthognathic surgery

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ABSTRACT

Objective: The present preliminary study investigated the usability of simulation-guided navigation osteotomy, in which the results of virtual surgery using simulation software with CT image data were transferred to the actual surgery.
Methods: Preoperative virtual surgery was performed in two patients who required two-jaw orthognathic surgeries, and the osteotomy design, as well as the bony segment movement direction and distance, was established. The maxillary segment was moved to the target location by checking the position three-dimensionally using a navigation system, and the mandible was moved to articulate with the maxilla. The preoperative simulation image and the postoperative three-dimensional image were superimposed, and the difference between the two images was measured to evaluate the accuracy of the surgery.
Results: The positional errors between the maxillary position established by simulation and the jaw position achieved in the actual surgery were clinically acceptable. The results suggested that use of a navigation system allows safer and more precise Le Fort I osteotomy.
Conclusion: Further analysis with more patients is necessary to clarify the effectiveness of the present method. However, this method may offer a new technique for orthognathic surgery by developing simulation software dedicated to orthognathic surgery allowing importing of CT image data directly to a navigation system.

1. Introduction

The diagnosis and treatment plan development of jaw deformities have been performed based on the analysis of cephalometric radiographs, facial images, and plaster models of the dentition. The direction and extent of bone fragment movement for orthognathic surgery are determined based on the preoperatively predicted occlusion [1]. However, improvement of facial appearance is also an important treatment goal for jaw deformities, as well as establishing a good occlusal relationship. Therefore, several facilities perform morphological evaluation of the skull using three-dimensional CT images. The development of simulation software has allowed preoperative prediction of the site and degree of bone interference during bony segment movement, as well as the maxillofacial skeletal morphology after bony segment movement, the effectiveness of which has been already reported [2–4].

Despite the accuracy of simulations using three-dimensional CT images, results obtained in a simulation cannot be effectively applied to clinical practice unless they can be compared with actual surgery. To achieve safe and precise surgery for jaw deformities, it is necessary to perform a preoperative simulation based on the treatment plan and to transfer this information to the actual surgery using a navigation system that identifies the operation site three-dimensionally [5,6].

In the present preliminary study, virtual two-jaw surgeries were performed using simulation software with preoperative CT data, and the osteotomy design, as well as the direction and distance of bony segment movement, was established. Simulation-guided navigation osteotomy was then performed, referring to the simulation results transferred to the navigation system. Furthermore, the

☆ Asian AOMS: Asian Association of Oral and Maxillofacial Surgeons; ASOMP: Asian Society of Oral and Maxillofacial Pathology; JSOP: Japanese Society of Oral Pathology; JSOMS: Japanese Society of Oral and Maxillofacial Surgeons; JSOM: Japanese Society of Oral Medicine; JAMI: Japanese Academy of Maxillofacial Implants.

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postoperative CT image and the simulated image were superimposed to evaluate the accuracy of the present surgical method.

2. Methods

The present study was performed with the approval of the IRB of our university, and the participants provided their written, informed consent. The subjects were two patients who required two-jaw orthognathic surgery. Informed consent regarding the treatment plan, surgical method, and simulation-guided navigation osteotomy was obtained.

CT data obtained immediately before the surgery and on postoperative day 14 were used. CT was performed with the mouth closed using a CT device (HiSpeed QX/I, GE Healthcare Japan Corporation, Tokyo, Japan) at a tube voltage of 120 kV, tube current of 260 mA, and a slice thickness of 1.25 mm. The obtained images were saved in DICOM (Digital Imaging and Communication in Medicine) format.

CT data were imported to the preoperative planning system (IGS Planning Work Station, BRAINLAB, Feldkirchen, Germany), and simulation consisting of three-dimensional image extraction of the upper and lower jaws, osteotomy line setting for the Le Fort I osteotomy and the bilateral sagittal split osteotomy (BSSO), and movement of the upper and lower jaws was performed using the simulation software (iPlan CMF 3.0, BRAINLAB). The jaw bone was split on the computer according to the incision line of the simulated Le Fort I osteotomy and BSSO to generate the virtual surgery postoperative image.

The navigation system used in the present surgery was an optical navigation system (KICK® Navigation System, BRAINLAB). Surgical simulation data obtained preoperatively were imported to the navigation system. A head band was placed around the head of the patient under general anesthesia, and a reference antenna was attached. The irregularities around the nose and eyes were scanned using a laser reflection, and interfacing laser registration was performed.

For Le Fort I osteotomy, the osteotomy line was drawn on the maxillary bone surface following the indicated osteotomy line shown on the navigation system screen. Osteotomy was then performed along the osteotomy line drawn on the maxillary bone surface using piezosurgery and a tracker, and the maxillary segment was mobilized by down-fracture using a bone separator. Using the image of the simulated repositioned maxillary segment shown on the navigation system screen, the bone segment was moved to the determined position relative to the external margins of the anterior nasal apertures, ANS, A-point, and bilateral canines as shown on the screen and by checking these points in the patient using a pointer. To apply plate fixation to a mobile maxilla at a new position, an intermaxillary occlusal splint prepared using the conventional method was first attached to the upper dentition. An image after movement of the maxillary segment was then displayed on the screen of the navigation system while confirming the positions of the lateral margin of the piriform aperture, ANS, point A, and bilateral canines of the maxillary segment using a pointer: the segment was moved to the position at which these points were consistent with those in the simulation image, and the lower jaw was guided to the upper jaw position for occlusion, in which the splint morphology was adjusted as needed, and stability of the maxillary segment without mobility at the new position even in occlusion between the lower and upper dentitions through the splint was confirmed. Intermaxillary anchorage was applied in this condition using elastics and fixation with absorbable mini plates.

When there was an error of more than 1.0 mm, re-registration was performed using 4 arbitrary points marked on the maxillary bone surface above the osteotomy line to maintain navigational accuracy. The positional relationship between the reference antenna and osteotomy line was registered preliminarily. Mandibular repositioning was performed following the movement of the maxilla. BSSO was performed by the conventional method, and the mandible was moved so that the mandibular dentition fit the bite splint attached to the maxillary dentition. Bony segments were fixed with a mini plate.

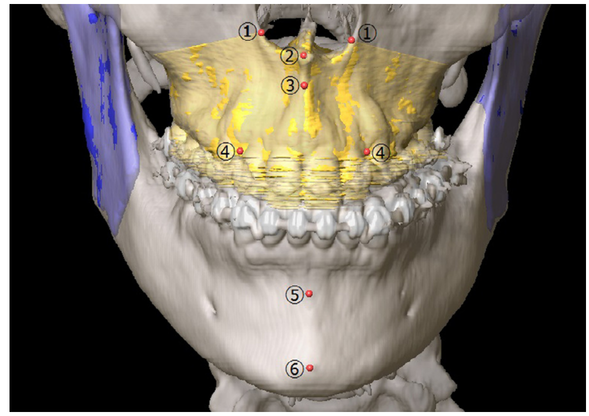

Fig. 1. Measurement points: ① resection stump of the external margins of the bilateral anterior nasal apertures, ② tip of the anterior nasal spine (ANS), ③ the deepest point on the concave outline of the upper labial alveolar process in the median-sagittal-plane (A-point), ④ mesial cervical area of the bilateral canines, ⑤ the deepest point on the concave outline of the lower labial alveolar process in the median-sagittal-plane (B-point), and ⑥ the most projecting median point on the anterior surface of the chin (Pog).

DICOM CT images taken on postoperative day 14 were imported to the IGS Planning Work Station, and the predicted image of the three-dimensional skull generated from the virtual surgery and the postoperative three-dimensional skull image were superimposed using the superimposition function of iPlan CMF 3.0. The difference between the images was measured to evaluate navigational accuracy during the actual surgery. Measurement points included the resection stump of the extramargin of the bilateral anterior nasal apertures, ANS, A-point, PNS, and the mesial cervical area of the canine in the upper jaw (6 points in total), and B-point and Pog in the lower jaw (2 points in total) (Figs. 1 and 2). The maximum distance between each point was measured 3 times in both the predicted postoperative image and the actual three-dimensional skull image, averaged and rounded off to one decimal place, and used as the measurement value. All measurements were performed by a non-operating surgeon.

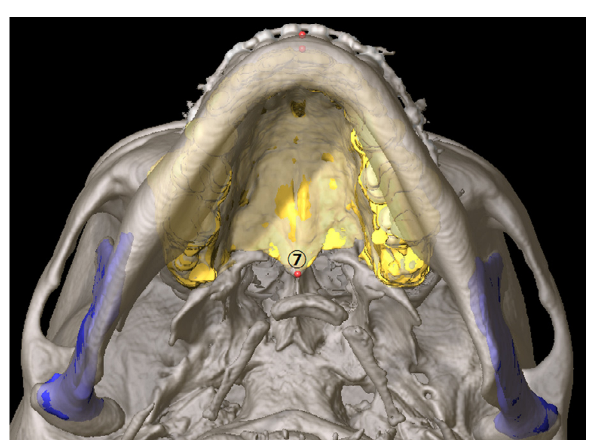

Fig. 2. Measurement point: ⑦ posterior nasal spine (PNS).